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Patent Application of

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for

Energy Recovery in Shoe Soles for Improved Athletic Performance

BACKGROUND

Improvements in shoe design over the last 40 years have primarily focused on increased comfort and stability. Aimed toward this goal, several patents describe springs, fluid or gas bladders, and elastic pads intended to cushion the contact with ground. A few recent designs, however, had a different goal, attempting to recover the energy normally expanded in the process of walking through the contact between the foot and ground. At least two patents (Ronen et al. US5042175, Sabol US5343636) explicitly include as a goal recovery of stride energy. There are also at least two commercial products intended to recover the energy expanded in the movement of the foot against ground: Nike Corporation introduced a few years ago sports shoes with "spring heels", together with the advertising slogan "what you put you get back". A specialty shoe manufacturer, Baldo of Italy (www.baldoamerica.com), manufactures women's shoes with an integral spring between the heel and ground. An additional product somewhat relevant to the present invention is the Spring-Eze elastic shoe insert (USD423.766). Spring-Eze is not aimed at energy recovery, but the concept of a shoe insert with elastic properties, as presented by Spring-Eze and certain prior art can be made applicable to energy recovery, as will be discussed later.

These earlier patents and products have had only limited commercial success. The limited market penetration is attributable to inadequacies of these existing designs, which do not take into consideration body weight and the different pattern of foot contact in various sport activities. In many situations, the limitations of the existing designs actually interfere with athletic activity, rather than support it. In contrast the present invention, for the first time, makes possible maximal energy recovery for individuals of different body weights, engaged in a broad range of athletic activities.

PRINCIPLE OF THE INVENTION

The essential element of walking, jogging, running, jumping, and other ambulatory athletic activities, is the recurrent intermittent contact of the legs with ground. These activities typically involve a repetitive sequence of events: First comes the contact of one leg with ground, which provides a fulcrum point to propel the athlete to the next step. During that time, all or part of the individual's weight is supported by pressure of the foot against ground, freeing the other leg to move forward. Once the other leg has been moved forward and placed on the ground, continuation of ambulation involves progressive application of the individual's weight on that other foot, until the first foot bears no weight and, in its turn, can be lifted on the ground and moved forward to execute the next step. There is thus during walking, jogging, etc., recurrent application of weight on each foot, followed by removal of that weight.

If a spring is placed between foot and ground at the contact point, that spring will be compressed by the applied weight. Subsequently, when the body's weight is shifted to the other foot, expansion of the spring can provide assistance in shifting that weight. Based on this scenario, springs or similar passive devices may assist ambulation and athletic activities. This has been recognized by the prior art cited above.

What has not been recognized in prior art or in existing commercial products, however, is that springs or other elastic devices can provide effective assistance in shifting the body's weight from one foot to the other, only when such springs are matched to the weight applied on them and to the type of activity. If the spring is excessively stiff, the applied weight will not compress it, and there will be no subsequent useful expansion. If the spring is too soft, its expansion will provide only little useful counter-pressure during the uplift of the foot. In fact, springs that are too soft, actually may impede walking by collapsing under the body's weight, while preventing firm contact with ground. Since the spring is compressed by the individual's weight, individuals of different body weight require springs of different stiffness, and the "one size fits all" approach of prior art cannot be successful.

A second and equally important consideration absent from prior art, is that the rate of movement of the feet against ground, and the rate of application of the body's weight against the spring, are critical in spring assistance of athletic activities. The frequency of the up and down movement of the legs, and the rate of acceleration of the foot against, and away from ground, vary according the speed of walking, and according to the type of athletic activity. For example, jogging requires more rapid up and down foot movement than walking. Speed running and jumping, in turn, involve even more rapid foot movement. Thus, a spring which expands at a particular rate, may be of substantial assistance in walking, but provide practically no help – or perhaps even impede – speed running or basket ball playing.

More specifically, compression of the shoe sole must occur at a rate that coincides with the rate of movement of the foot against the ground, and the subsequent expansion must occur at the same time the foot is lifted away from the ground. If expansion takes place

only after the foot has lost contact with ground, it provides no help to that movement, and the energy stored in the spring is wasted. If expansion occurs too early, e.g. while the foot still is moving toward the ground, or during the brief moment the foot is resting on the ground, expansion actually interferes the natural movement. Likewise, if the spring is too soft, the effect is similar to walking in sand or mud, and the spring actually impedes walking or running rather than aid it.

In order for a shoe containing a spring or an elastic pad to provide assistance in leg movement, energy release must coincide in time with the upward movement of the foot, and must be neither faster nor slower than the wearer's own rhythmic up-and-down movement. In other words, the rebound of the elastic support must occur in synchrony with the human movement. Only if the release of energy by the elastic pad or by the spring occurs at the same time, and at the same rate as the reversal of movement, can it provide significant assistance to walking, running, jumping, and other sports activities. Each of these athletic activities involves very different rate of movement of the legs against ground. Since, as discussed below in greater detail, a spring's expansion characteristics depend on its stiffness, a spring of any given stiffness cannot be effective for the whole range of sports activities.

The present invention recognizes that the challenge in creating an effective spring-assisted shoe, is in matching the spring to the weight compressing it, and to the type of movement. To achieve this goal, it is necessary to consider the time-domain aspects of the behavior of compressed springs, described by Hooke's Law. This Law defines the relationship between the frequency of the harmonic motion f of any given spring or elastic pad to both the spring constant k, which is a measure of "stiffness" of that spring, and to the mass m of the compressing body:

$$f = 0.159 \sqrt{(k/m)} \qquad \text{(eq. 1)}$$

Hooke's Law can be related to athletic movement if we map the repetitive up-and -own movement of the legs to the time domain. According to this model, the reciprocal leg movement may be viewed as harmonic motion, the period of which increases when leg movement is more rapid. The goal of the present invention may then be restated more simply as synchronization of the harmonic motion of locomotion, with the harmonic motion of the loaded spring contained in the shoes. When these two motions are synchronized, the energy of the down-step is returned by the spring at the exact moment of the following up-step.

In athletic activities which involve repeated leg movements at fixed frequency, e.g. running, there is the added possibility of successive footsteps storing more and more energy in the spring, leading to driven harmonic motion. In this situation, if the frequency of vibration of the loaded spring matches the frequency of leg movement, resonance will ensue. Resonance of these two harmonic motions, i.e. that of the legs and of the shoes, can produce very marked enhancement of successive leg movements, as long as their frequency matches the frequency f defined by Hooke's Law for an individual with mass m, and shoes with Hooke's Spring Constant k.

As already noted, the rate of leg movement varies greatly between different types of athletic activity. Because of this, it is clear that any given spring or elastic pad cannot be suitable for the entire range of human ambulatoryand thletic activities. Such a spring may assist certain activities, but actually interfere with other activities involving either slower or faster movement. For example shoes which are “tuned” to track running, are not likely to provide useful energy recovery in leisurely walking.

Moreover, inspection of eq.1 reveals that the period of harmonic motion depends not only on spring stiffness, but also on the mass of the compressing body – i.e. body weight. For example shoes designed for long-distance running, will provide optimal energy recovery only for individuals of a certain body weight. Individuals either heavier or lighter will receive lesser benefit from these shoes, possibly may receive no benefit at all, or actually find these same shoes an obstacle to their optimal athletic performance Consequently, body weight plays an essential part in determining the desired properties of the optimal spring or elastic pad. A spring suited for an individual weighing, say, 250 lb., would be far too stiff for another person weighing 150 lb., even if both individuals are engaged in the exact same athletic activity.

The goal of the present invention is to achieve storage of the energy of downward leg movement, and to release this stored energy at a point in time, and at a rate, which are both consistent with both the individual’s weight and the type of athletic activity, so as to assist in upward movement of the leg. The principle of the present invention is to tune the elastic characteristics of the shoe to the different athletic activities, and to the different body weights of athletes.

In conclusion, the present invention applies physical laws to the role of shoes in athletic performance. This invention recognizes that any single spring assembly or elastic device, however ingeniously constructed, cannot provide optimal capture and return of the energy of leg movement across all situations. To overcome this difficulty, the present invention introduces two innovations: (a) it provides shoes with different elastic properties for different athletic activities of the same individual, and (b) it makes available shoes with different elastic properties, for individuals of different body weights engaged in the same athletic activity.

DETAILS OF THE INVENTION

The present invention requires for each individual athlete, shoes with different elastic properties for different athletic activities. It also requires shoes of different elastic properties for individuals of different body weight. The elastic properties of the shoe sole/heel are completely determined by the spring constant *k* of the sole/heel. There are a number of ways the invention can be reduced to practice:

1. Shoes where Hooke's spring constant is mechanically or electronically adjustable over a continuous range, without the necessity of taking the shoes off the feet. Such shoes are ideal from the user's viewpoint, but require complex technology, which has not previously been applied to shoe manufacture.

2. Shoes where the spring constant *k* is adjustable through the manual addition or removal of springs or elastic pads, or shoes incorporating bladders which can be filled with fluid or gas to different level. Such shoes, as well, are complex to manufacture.

3. Shoes manufactured with a fixed spring constant *k*. The great advantage of this approach is the inherent simplicity, which translates to durability and low cost. The disadvantage is that several shoes, each with a different spring constant, are required for any individual who wishes to engage in a number of different sports activities, e.g. basketball shoes, jogging shoes, jumping shoes, etc., and that different individuals require different shoes for the same sports activity.

The first two approaches offer greater flexibility than the approach described last. However, these approaches are not compatible with consumer expectations for lightweight, durable and inexpensive shoes. Fluid-filled bladders, as proposed in earlier inventions cited above, are likely to result in a shoe considerably heavier than standard shoes. Springs may not add quite as much weight as fluid bladders; however, there are significant technical problems related to bonding of metal springs with the softer materials of the shoe, so that durability may pose a serious challenge. Cost, likewise, is likely to be excessive for most common uses. The same considerations apply, with greater vigor, to shoe designs with continuously variable spring constant, with the additional reservation that cost is likely to be prohibitive for all but the most demanding applications. These first two approaches, even though definitely within the scope of the present invention, at present are not suitable for mass production.

On the other hand the approach listed last, namely the use of elastic materials to create shoes with a fixed spring constant, can be adapted readily to manufacture and distribution, and its benefits will be immediately available to the public. Elastic materials are now available at wide range of Hooke's spring constants, so that shoes of a fixed spring constant can be manufactured in a broad range of spring constants. The technology of forming elastic materials into a sole/heel assembly, and the technology of bonding an elastic sole/heel assembly to the shoe uppers, are well established, and are

employed to manufacture nearly all athletic shoes currently on the market. These technologies are mature and inexpensive, and durability does not constitute an issue. Using this approach, shoes with higher spring constant can be manufactured simply through use of stiffer elastic sole/heel material, and shoes of lower spring constant through the use of softer sole/heel elastic material. Except for the difference in spring constant of the shoe/heel assembly, it is not be necessary to change the design or manufacture process of the shoes in any way. These advantages make shoes with a fixed spring constant the preferred embodiment of the present invention.

Because shoes manufactured in this way with different spring constants, may look exactly alike, an essential part of the preferred embodiment is to provide means for distinguishing, in each shoe size, between shoes of different spring constants. Accordingly, shoes manufactured following the present invention will need to carry markings not only of size, but also of the shoe's spring constant. Of course these markings do not need to be numerical or even explicit; different spring constants may be color-coded, e.g. blue for low spring constant, white for intermediate, and red for high spring constant. Multiple alternative marking schemes are possible; manufacturers may elect to associate different spring constants with different shoe appearance, different model names, or even with different shoe construction, with high spring constants being, e.g. associated with sturdier shoes. As long as these markings or structural differences are related in a non-random fashion to the spring constant of the shoes, they will serve the purpose of the present invention.

One drawback associated with this embodiment, is the need to use different shoes for different type of athletic activity. As regards the individual athlete, most athletes concentrate on one, or at the most two types of athletic activity, so that for the individual this is not a severe constraint. Manufacturers and retailers, on the other hand, will need to stock at each shoe size a number of shoes, differing only in the spring constant of the sole/heel, since according to the present invention, different spring constants are required for different activities, and according to the preferred embodiment of the invention, each pair of shoes has a fixed spring constant.

Nevertheless, the number of different spring constants which retailers will need to stock is not nearly as high as it appears at first sight. According to Hooke's Law, the frequency of harmonic vibration depends not only on the stiffness of the spring or elastic material, but also inversely on the mass (eq. 1). A shoe of a given sole spring constant k may therefore be employed by one particular individual for an athletic activity requiring a particular frequency of harmonic motion, but the same shoe may be used by a second individual weighing twice as much, for an athletic activity where the frequency of harmonic motion is one half of the optimal frequency for the first athlet[illegible]ivity. For example, a shoe suitable for a lightweight individual for rapid running, ca[illegible] provide optimal energy recovery for a heavier individual undertaking a leisurely walk.

Consequently, it would be necessary to manufacture each shoe size only in a limited number of sole/heel spring constants, in order to meet the goals of the preferred embodiment of the present invention. Depending upon the wearer's body weight, a shoe

with a given spring constant will be suitable for a particular type of athletic activity; a shoe with lower stiffness would be appropriate for a different athletic activity and provide maximal energy recovery in that activity. Although a second individual with the same foot size but a different body weight, would not be able to use the same shoe for the same athletic activity as the first individual, he or she nonetheless will be able to use the same shoe for another type of athletic activity, or find a shoe with different spring constant which would provide optimal energy recovery while engaging in the same sports activity as the first individual. The salient point here is that a shoe of a given spring constant may provide optimal service for more than one individual. That same shoe may be appropriate for one individual for walking, while for a second individual the shoe will be appropriate for fast running. Both individuals in this example will gain optimal energy recovery from the shoe – but not for the same athletic activity. Accordingly the preferred implementation only requires the retailer to maintain a stock of shoes with a limited number of different spring constants at each shoe size. The needs of a particular sport activity, and the needs of any particular individual, will be satisfied in all but extreme cases, simply through selection from that available range of spring constants.

Because cost, simplicity, and durability are the critical factors in the utility of shoes and similar common objects, the preferred embodiment of the present invention thus is a series of shoes of the same size, all with elastic sole and heel, but with different Hooke's spring constant. Furthermore, a similar series of shoes, differing only in spring constant, will be made available at each shoe size. It is already well known in the art of shoemaking to manufacture sole/heel ensembles of different stiffness, and to reliably bond such sole/heel ensembles to the shoe uppers. The novel teaching of the present invention is to use the existing manufacturing methods to provide a series of shoes, each with a different spring constant, at each shoe size, and to have shoes of each spring constant marked in some way, so that the majority of athletes are able to find a shoe with the appropriate spring constant to provide optimal energy recovery during a specific athletic activity or activities. Such range of shoes within each shoe size does not presently exist, and its introduction is the essence of the present invention.

A second embodiment which also may find some applicability, is the use of elastic pads, either between the foot and the shoe sole, or attached to the shoe externally, between the sole and ground. This embodiment satisfies approach (b) at the beginning of this section, i.e. shoes where the spring constant may be changed to suit different operational requirements, while retaining the low weight advantage of the preferred embodiment. However shoes of current design may not be able to accommodate internal pads of the thickness required to achieve the required spring constant. Externally attached pads raise significant issues of durability, For these reasons, attached elastic pads are not likely to see extensive use.